A PEPSE® Case Study on Retractable Packings

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I. Background:

In late 1995, Kansas City Power and Light (KCPL) installed retractable packing on their Montrose Unit 1 turbine. Performance tests were performed before and after the packing were installed in order to determine the performance effect of the packing. The energy balance computer program PEPSE (Performance Evaluation of Power System Efficiencies) was used to evaluate the test results.

KCPL personnel originally developed the PEPSE model of Montrose Unit 1. This model was reviewed and modified by Performance Engineering, Inc. (PEI) in early 1996. In addition, PEI added the capability to the model to evaluate test data. This was done using the Special Option 6 input option.

Results from the before and after test data using the PEPSE model indicate a performance improvement in Montrose Unit 1. An improvement of approximately 2 MW and a turbine cycle heat rate decrease of approximately 80 BTU/KW-hr were noted. Assuming an average boiler efficiency of 85%, this turbine cycle heat rate improvement would result in a decrease in net plant heat rate of approximately 100 BTU/KW-hr.

II. Unit Description:

A. General Station

The KCPL Montrose station consists of three coal fired reheat generating units. The current station net capacity is 485 MW. Units 1 and 2 are General Electric duplicate units with Combustion Engineering duplicate boilers. Unit 1went into commercial operation in July of 1958 and was followed by unit 2 in April of 1960. Montrose unit 3 has a Westinghouse turbine with steam supplied from a Combustion Engineering boiler similar to units 1 and 2. Unit 3 was placed in service in May of 1964.

B. Turbine

Montrose unit 1 turbine is a horizontal, tandem compound unit with one single-flow high pressure (HP) turbine, one single-flow intermediate pressure turbine (IP) and one double flow low pressure (LP) turbine. It was designed for throttle conditions of 1815 psia, 1000 °F with reheat to 1000 °F. Guaranteed throttle flow is 1,200,000 lb./hr. At 1.5 Hg" back pressure this was to produce 175 MW gross (165.25 net) with a net unit heat rate of 9,779 Btu/Kwh at 89% boiler efficiency. The condensate and feedwater systems consist of three 50% capacity condensate pumps and two 50% motor driven boiler feed pumps. There are four closed low pressure heaters, a deaerator and two closed high pressure heaters. A copy of the original A/E turbine cycle heat balance is shown in Figure 1.

C. Boiler

The Montrose unit 1 steam generator is a balanced draft unit designed for coal firing with tilting tangential burners and utilizes circulation pumps to insure positive boiler circulation. The unit uses two half capacity FD fans and two half capacity ID fans. There are also exhauster fans on each of the five Raymond bowl mills. The unit was originally designed to utilize a midwestern bituminous coal, however, the entire station was converted to low sulfur Power River Basin (PRB) coal in 1980. As a result of this conversion the units were all derated and additional precipitator surface was added.

D. History

At the time of their installation the Montrose units were the largest and most efficient units in the KCPL system. From commercial operation through the late 70's they were baseloaded and averaged 60 to 65% capacity factors. As larger more efficient units were added to the system the capacity factors decreased until the conversion to western (PRB) coal. Use of the PRB coal has resulted in a substantially lower fuel cost. The Montrose units are now operated with annual capacity factors in the 65 to 70% range. With other units in the system operating at lower total costs, the Montrose units are used extensively to follow system load and for off-system interchange sales.

III. Retractable Packing

A. TurboCare® Proposal:

In 1995 KCPL personnel were contacted by representatives of *TurboCare®* who submitted a proposal for the installation of Brandon® retractable packing in the Montrose unit 1 turbine. Retractable packing provides a variable clearance depending on the steam operating pressure. In effect this means that the packing can retract during transient periods such as start ups when thermal expansion and harmonic induced vibration often cause conventional turbine packing to make contact with the rotating elements or "rub". There are two negative affects of this contact. The first is to damage or wear the packing, thus opening the clearance and reducing the packing effectiveness. The second is vibration which can lead to wear or damage to other turbine components.

The benefits which *TurboCare®* claimed in their proposal included the following:

- Improved unit availability
- Eliminate the supply, planning and labor costs associated with installing new packing at every outage.
- Reduce blade tip seal wear and increase their operating lives.
- Allow for reduction of blade tip seal clearances below that of the original design
- Significantly reduce fuel consumption
- Significantly reduce fuel combustion emissions.

TurboCare® also prepared estimates of fuel savings associated with the use of the retractable packing for Montrose unit 1. These savings were associated with retrofitting the unit HP and IP turbines with new packing and returning the blade tip radial clearances to their design values. *TurboCare®* also proposed a 0.015" longer tip seal which would further reduce the clearances and thus produce even greater savings. KCPL agreed to use the longer tip seals. The summary of the *TurboCare®* proposal is contained in Appendix 2. This includes the assumptions, estimated savings and a description of the actual work involved.

B. KCPL Savings Estimates:

In order to verify the *TurboCare®* savings estimates, KCPL personnel reviewed the assumptions used by *TurboCare®* and modified certain values. These included the fuel cost and the replacement power costs based on more recent data than that provided originally to *TurboCare®*. The cost of the packing was capitalized and assessed versus three different estimates of life expectancy (5, 10 and 20 years). A benefit cost ratio was calculated for each case. These ratios all provided for a positive return. It was also noted that even if the estimated performance improvements from *TurboCare®* were twice the actual savings, the benefit cost ratios would still be positive. Based on this assessment the decision was made to utilize the retractable packing and the reduced clearance spill strips.

C. *Testing and Installation:*

In October of 1995 the KCPL Performance Engineering Test Crew conducted a turbine valves-wide-open (VWO) test of Montrose Unit1. The purpose of this test was to verify the turbine conditions before the outage. In November the unit was taken out of service for the planned outage. In addition to the installation of the retractable packing there were several other significant turbine repairs performed. These included the replacement of the 1st stage buckets (blades), refurbished the nozzle plates (1st stage stationary blades), installation of the reduced clearance HP/IP spill strips, and several major diaphragm repairs. Though not related to the turbine work, this outage also featured the installation of oil-fired ductburners to increase mill capacity. In February of 1996 the test crew returned to the station and performed another turbine VWO test in order to quantify the difference in performance before and after the outage.

IV. PEPSE Model:

A PEPSE model of Montrose Unit 1 developed by KCPL personnel. This model appears in Appendix 3. PEI reviewed this model and made some minor changes and adjustments. No geometry changes were made, only input changes. The adjusted "design" model results closely match the vendor heat balance diagrams.

Subsequent to adjusting the model, a Special Option 6 input file was developed using the "design" model as a base. Data from the before and after tests was inserted in two separate files of the Special Option 6 model. Using this technique, the PEPSE results from the Standardization Steps of the two Special Option 6 models (using the two sets of test data from October 1995 and February 1996) were compared.

In order to achieve consistent results using Special Option 6, the Standardization Step of Special Option 6 was modified slightly for both sets of test data. Special Option 1 was deleted from the Standardization Step, and the Benchmark Step flow was used for the Standardization Step. This was required because the two sets of data were at different throttle conditions. When the throttle flows were initially standardized (or "corrected") using Special Option 1, the results showed vastly different throttle flows for the standardized test results. A valid comparison was not achievable. Using the same throttle flows for both allowed a valid comparison.

V. Results:

Results from the Special Option 6 PEPSE computer models show a gain of 1.99 MW and a decrease of 84 BTU/KW-hr in turbine cycle heat rate after the outage. It is not possible to determine how much of these improvements is the result of the installation of the packing as opposed to the other turbine work completed during the outage. A summary of the test conditions and the standardized conditions generated by the PEPSE model are contained in Appendix 4.

VI. Conclusions:

The installation of the retractable packing, and other turbine work has afforded the KCPL Montrose unit 1 an increase in capacity of 1.99 MW and an improvement in turbine cycle heat rate of 84 Btu/Kwh. After adjusting for the boiler efficiency of approximately 85% the net plant heat rate improvement is estimated to be 99 Btu/Kwh. Though the magnitude of these improvements is not as large as the vendor predicted, the savings generated is still substantial. Using revised assumptions of 63% capacity factor, $1.00/MMBtu and $3.75 /MW-Hr the annual savings would be as follows:

Fuel Cost Savings:

= 99 Btu/Kwh x 150 MW (net capacity) x 63% Capacity Factor x 8760 Hr/Year x $1.00/MMBtu
= $81,954 (per year)

Capacity Cost Savings:

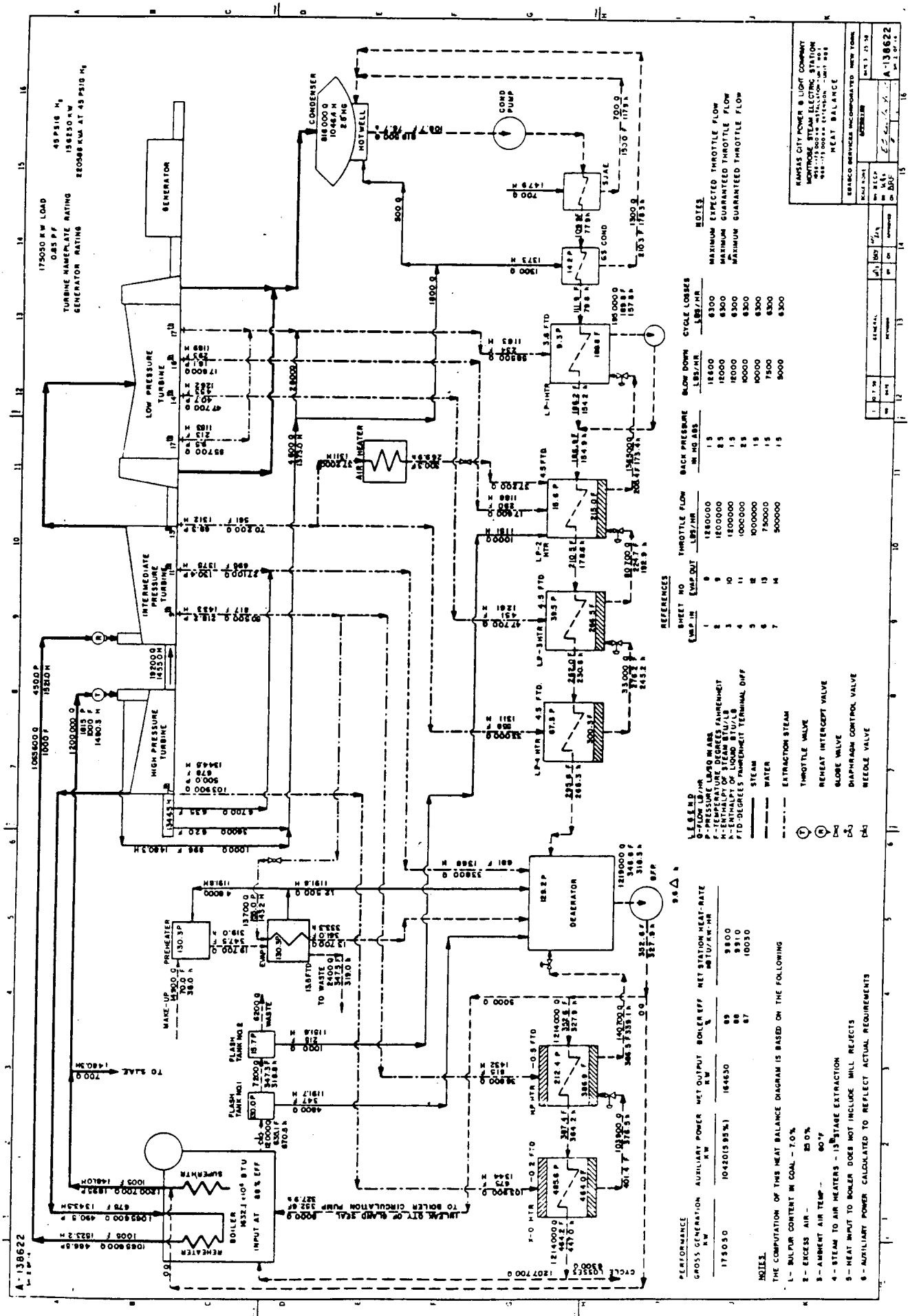
= 1.99 MW improvement x 8760 Hr x 63% Capacity Factor x $3.75/Mw-Hr
= $41,184

Total Savings:

= Fuel Cost Savings + Capacity Cost Savings = $81,954 + 41,184
= $ 123,138

The original capital cost estimate was $160,000. This resulted in an annual fixed charge of $61,824. Compared to the savings of $123, 138 this results in a benefit to cost ratio of 1.99. Stated differently this project should pay for its fixed charge rate in approximately 6 months.

VII. Appendix 1 Montrose Unit 1 Vendor Heat Balance



VIII. Appendix 2 Summary of TurboCare® Proposal for KCPL Montrose Unit 1

Assumptions:		Estimated Savings/Improvement:	
Turbine Capacity	156,000 KW	Turbine Capacity:	+3037 KW
Net Plant Heat Rate	10,469 Btu/Kwh	Net Plant Heat Rate:	-188 Btu/Kwh
Annual Capacity Factor	63%	Capacity Factor:	No Change
Fuel Cost	$1.00 /MMBtu	Annual Fuel Savings	$162,114
Capacity Cost	$15.00 /MW-Hr	Increased Capacity:	$251,409
Option:	Retractable Packing and Reduced Clearance Spill Strips	Total Annual Savings:	$413,523

Scope of Work:

OPTION I

The budgetary estimate to retrofit the referenced HP/IP turbine with *TurboCare*®'s patented Brandon® Retractable Packing is $160,000.00, and includes the following parts and services:

- 19 rows of new and modified Brandon® Retractable Packing. Rings in the N1 and N2 packing boxes will be modified to our retractable design. Nominal radial clearance for Brandon® Retractable Packing will be the same as conventional packing design clearance but not less than 0.020". Packing is manufactured to be concentric with the rotor, provided that turbine packing holders are not distorted. Unless specifically stated otherwise in writing by the undersigned, minimum nominal radial clearance of all Brandon® Retractable Packing will be 0.020". Packing rings are manufactured to achieve specified operating clearances. Since assembly clearances typically differ from operating clearances due to turbine component distortion; there may be some normal deviation of clearances at assembly time.

- Supply springs associated with the listed packing.

- Perform turbine pre-measurement distortion assessment and installation of Brandon® Retractable Packing and *TurboCare*® - supplied conventional packing rings. These services include precision unit distortion measurements, machining of butt clearances, machining of the retaining pin slots, and installation of the packing rings into the packing ring holders. Final staking of the packing ring retaining pins will be the responsibility of KCPL. The listed services are provided for a maximum of 152 man-hours at the project site including normal shift standby time. Additional work or delays not caused by *TurboCare*® that result in additional man-hours required to complete the listed services shall be invoiced according to *TurboCare*® Field Services rates, and shall entitle *TurboCare*® to extra time and living expenses to perform the listed services.

  Actual number of installation technicians required and shifts to be worked will be determined by agreement between *TurboCare*® and KCPL personnel prior to the unit outage. Additional services beyond those specified herein are available at published daily rates. Note that the quoted price does not include machining that is required for custom-fitting of packing into excessively distorted diaphragms and/or packing holders. Distortion is considered excessive when horizontal and vertical packing hook diameters differ by more than 0.040". Shipping costs associated with any custom-fitting shall be invoiced at cost. If tip seal removal and/or installation is provided by *TurboCare*®, then blast cleaning of tip seal appendage area should be performed by KCPL after existing tip seals are removed, but before new seals are installed.

- Technical services associated with the packing; including up to five (5) days of technical direction and distortion pre-measurement of the unit during the scheduled outage. Listed services associated with the installation of Brandon® Retractable Packing include a total of three round-trip travel fares for inspection and installation technicians. Additional travel costs associated with delays or additional work shall be invoiced according to *TurboCare*® Field Service rates.

OPTION II

The price to supply the referenced HP/IP turbine with conventional spill strips is $11,160.00 and includes the following:

- Supply up to 248 segments Conventional Blade-tip Seals and springs for HP/IP stages 2-13. *TurboCare*® recommends reducing radial tip seal clearances by 0.015" below conventional design, but not to less than a nominal radial clearance of 0.036". Reduction of nominal clearances are achieved by manufacturing spill strip teeth 0.015" longer than conventional design.

These prices are offered in package form, and it is necessary to install Brandon® Retractable Packing in a complete rotating element (i.e. HP/IP and/or LP turbine) versus only the and-packing, mid-span packing, HP section or IP section alone. The following items should be provided by KCPL to perform the workscope described above:

- Crane and rigger to set up tooling and packing ring holders for measurement and installation of packing. In order to minimize crane-time and stand-by time required, KCPL should place diaphragms and packing holders in a horizontal-joint upward (∪) orientation. This is facilitated by a simple floor-rack constructed of "two-by-fours".

- Removal of existing packing and repair of packing pin holes if required.

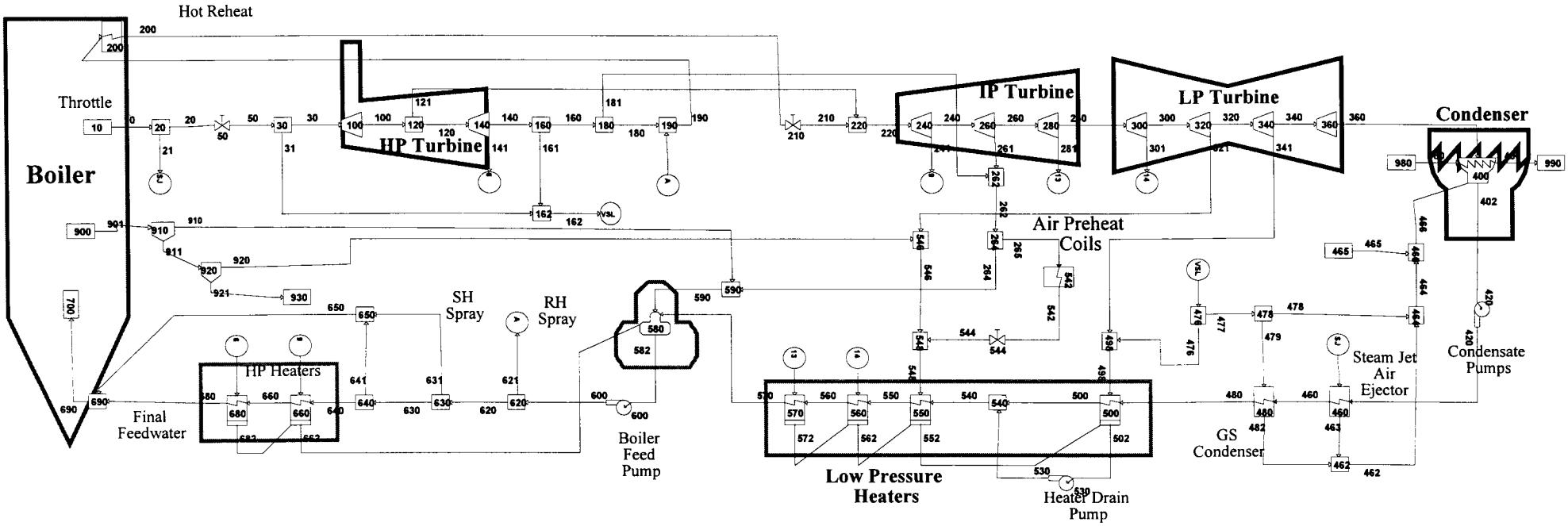
- Supply of butt-key screws

- Electrician and/or access to 480 volt electrical service.

- Craft labor (1 person) to assist as required.

- Potable water and washroom facilities for use by installation personnel.

IX Appendix 3 PEPSE Model Schematic



Montrose Unit 1 Turbine Cycle Model

X. Appendix 4 Summary of Test and Standardized Conditions

		Pre-outage Test	Post Outage Test	Difference
Test Date		10/26/95	2/16/96	
As-Tested Conditions				
Gross Load	Megawatts	168.0	170.9	
Throttle Flow	Klb/Hr	1,242,251	1,200,939	
Throttle Temp	Deg F	993	1,017	
Throttle Pressure	Psia	1,604	1,701	
Hot Reheat Temperature	Deg F	1,001	1,012	
Hot Reheat Pressure	Psia	444	430	
Back Pressure	Hg"	2.3	1.6	
HP TurbineEfficiency	Percent	81.7	79.4	
IP Turbine Efficiency	Percent	93.3	95.4	
LP Turbine Efficiency	Percent	69.8	67.9	
Turbine Cycle Heatrate [1]	Btu/Kwh	8,665	8,368	
Corrected to Standard Conditions [3]				
Gross Load	Megawatts	173.6	175.6	**2.0**
Throttle Flow	Klb/Hr	1,260,000	1,260,000	**0**
Throttle Temp	Deg F	1,000	1,000	**0**
Throttle Pressure	Psia	1,815	1,815	**0**
Hot Reheat Temperature	Deg F	1,000	1,000	**0**
Hot Reheat Pressure	Psia	453	436	**-17**
Back Pressure	Hg"	1.5	1.5	**0.0**
HP Turbine Efficiency	Percent	80.6	79.0	**-1.6**
IP Turbine Efficiency	Percent	93.3	95.4	**2.1**
LP Turbine Efficiency	Percent	66.2	66.7	**0.5**
Turbine Cycle Heatrate	Btu/Kwh	8,517	8,428	**-89**
Net Plant Heat Rate [2]	Btu/Kwh	9,779	9,676	**-103**

Notes:
1. Gross Turbine Cycle heat rate
2. Assuming an 85% Boiler Efficiency
3. Corrected to the same throttle flow as noted elsewhere